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Evaluation of the Effectiveness of Simulation for M4 Marksmanship Training

Ashley Stephens¹ and Philip Temby²

¹Joint Operations and Analysis Division

²Land Division

Defence Science and Technology Organisation

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ABSTRACT

Simulation is widely used within the Australian Army and other defence forces for marksmanship training. However, there is a lack of data that quantifies the training effectiveness of these devices, and informs the appropriate mix of live-fire and simulation. This report documents a study which measured the effect of additional simulator training on a basic live-fire qualification task with the M4 weapon. The study was conducted with thirty-six Australian Defence Force personnel enrolled in an Army training course. Following initial marksmanship training, one group (n=18) completed additional simulator training while the other group (n=18) proceeded straight to live-fire qualification. The group that received additional training in the simulator achieved slightly faster live-fire qualification; however trainees in both groups required numerous attempts to pass. The findings show that the simulator training had a small, positive benefit, but that the overall training was not particularly satisfactory. The report outlines reasons for these findings and provides recommendations for future studies that could explore more effective training methodologies.

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Evaluation of the Effectiveness of Simulation for M4 Marksmanship Training

Executive Summary

Simulation is widely used within the Australian Army and other defence forces for marksmanship training. The cost of live ammunition, the availability and accessibility of live-fire ranges, and administrative overheads associated with planning and conducting live-fire practices all make the use of marksmanship simulators an attractive training option. Anecdotally, it is believed that the use of marksmanship simulation leads to savings in overall training time and improved live-fire performance; however there is little empirical data to support this belief. Furthermore, within the Australian Defence Force (ADF), there is a lack of data to inform the appropriate mix of simulator and live-fire training needed to achieve specific training objectives.

This report documents the outcomes of a study examining the use of the Weapons Training Simulation System (WTSS) for basic marksmanship training on an Australian Army training course. The aim was to measure the effect of additional simulator training on subsequent live-fire qualification. Furthermore, it was anticipated that the study would provide Army with objective data to inform the use of the WTSS for basic marksmanship training. The study was conducted by DSTO Land Operations Division under Task ARM 07/163: Training, Learning and Performance.

Thirty six ADF personnel enrolled on the course took part in the study. As part of the course, trainees were required to pass a qualification task using the M4 weapon with iron sights on the live-fire range. After all personnel conducted initial marksmanship training, one group conducted the qualification practice three times in the simulator prior to conducting three qualification attempts on the live-fire range; the second group conducted three qualification attempts on the live-fire range with no prior qualification practices in the simulator. There was no significant difference between the two groups based on their qualification scores but the group that conducted simulator training achieved a slightly higher pass rate after two qualification attempts. The findings suggest that the additional simulator training had a small, positive effect on subsequent live-fire performance.

Overall, however, it took trainees numerous attempts to qualify and it can be concluded that the additional simulator training, in conjunction with the initial marksmanship training was not particularly satisfactory. Reasons for this outcome include a lack of trainee experience with the M4 weapon and iron sights, limitations with the simulator target imagery, and few opportunities for individual coaching. It is recommended that these issues are addressed in order to develop a more effective marksmanship training methodology using a combination of simulation and live-fire.

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The data collected in this study will provide a basis for achieving this outcome. In conclusion, this study has clearly shown that the simulator is only one of many factors that need to be considered if effective training outcomes are to be achieved; failure to do so means that questions regarding the appropriate mix of simulator and live-fire training cannot be answered.

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Authors

Ashley Stephens

Joint Operations and Analysis Division

Ashley Stephens holds a PhD in Physical and Inorganic Chemistry from Adelaide University. He joined DSTO Land Operations Division in 2001 and has conducted Operations Analysis in support of a range of areas including the AEF, Urban Operations, Special Operations and Training and Simulation. He is currently working as a Senior Operations Research Scientist in Joint Operations and Analysis Division.

Philip Temby

Land Division

Philip Temby is a Research Scientist in DSTO's Land Division. He holds a Bachelor of Science Degree and First Class Honours Degree in Psychology from the University of Adelaide. He also holds a Master of Psychology Degree from the University of South Australia and is a Registered Psychologist in Australia. He joined DSTO in 2002 and has conducted human factors studies in support to various Australian Army and Special Forces projects. His research interests include cognition, human performance measurement, resilience, skill development, and team training.

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Acronyms

ADF	Australian Defence Force
DSTO	Defence Science and Technology Organisation
EST	Engagement Skills Trainer
HPS	Highest Possible Score
ISMT	Indoor Simulated Marksmanship Trainer
LF	Live-fire (marksmanship practice)
LOD	Land Operations Division
M4	M4A1 Modular Weapon System
MPI	Mean Point of Impact
PT	Percent Transfer
PWT	Personal Weapons Test
SAT	Small Arms Trainer
SD	Standard Deviation
SPSS	Statistical Package for the Social Sciences
TER	Transfer Effectiveness Ratio
WTSS	Weapons Training Simulation System

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1. Introduction

Marksmanship is a fundamental skill required by all soldiers which involves the use of a personal weapon to provide accurate and effective fire to the maximum effective range of that weapon [1]. Consequently, marksmanship is a core component of individual training, both within the Australian Army and within other armies worldwide. Marksmanship training is traditionally conducted on live-fire ranges. In particular, live-fire qualification is usually required to demonstrate marksmanship proficiency and achieve mandated training competencies. However, the cost of live ammunition, the availability and accessibility of live-fire ranges, and administrative overheads associated with planning and conducting live-fire practices make the use of marksmanship simulators an attractive alternative for marksmanship training [2-4]. The Australian Defence Force (ADF) has used simulation for marksmanship training since 2000 [5]¹. Similar systems are currently employed by the Canadian Defence Force, US Army and US Marine Corps.

Small arms marksmanship simulators are typically indoor laser-based devices which can support training for a range of weapon systems, including pistols, rifles, machine guns and anti-armour weapons. In these simulators, firers aim a modified weapon at a target image on a screen. When the firer pulls the trigger, the weapon fires a laser at the target, a camera detects the position where the laser hits the on-screen target, and the system calculates the fall-of-shot. The system can provide this information to the firer, as well as feedback on factors such as the degree of movement of the weapon barrel, which helps firers to correct and refine their marksmanship technique.

The use of marksmanship simulators can potentially lead to more efficient and effective training, compared with traditional instruction, through a reduction in live training time and ammunition usage, as well as a measurable improvement in subsequent live-fire performance. In addition, firer performance in the simulator can potentially be used to determine readiness for live-fire qualification. This outcome would also lead to more efficient training, as it would help to avoid wasting ammunition on trainees who were not ready to attempt live-fire qualification. However, there is a lack of empirical evidence regarding the efficiency and effectiveness of simulation-based marksmanship training [6]. Consequently, there is a need for further research to address the lack of data and guide the effective use of marksmanship simulation in military training programs.

This report documents the outcomes of a study examining the use of simulation for basic marksmanship training on an Australian Army training course. This work was undertaken by Defence Science and Technology Organisation (DSTO) Land Operations Division (LOD) as part of broader research program to assist Army achieve more efficient and effective training outcomes through the use of simulation. In support of this requirement, the current study investigated the utility of additional simulator training on subsequent live-fire qualification for a basic marksmanship task using the M4 weapon with iron sights. In this report, we present empirical evidence for transfer of training from the simulator to

¹ The ADF marksmanship simulator is the Weapons Training Simulation System (WTSS) which is manufactured by Meggitt Training Systems Inc.

the live-fire environment. We also demonstrate that the simulator is only one of several factors that contribute to effective training.

1.1 Previous research on training efficiency and effectiveness of marksmanship simulators

Anecdotally, marksmanship simulators are believed to be effective environments for trainees to become familiar with different weapon systems, as well as learning the principles of marksmanship and receiving coaching. This is because marksmanship simulators are generally more available and accessible than live-fire ranges, as well as providing a benign environment in which to learn, particularly for trainees with limited or no experience with live-fire weapons. The latter aspect is believed to lead to faster skill acquisition and hence more efficient training during the early stages of learning. Overall, marksmanship simulation appears to be viewed as an effective supplement (but not replacement) for live-fire, when used in conjunction with marksmanship coaching².

Beyond this anecdotal evidence, there are few studies that provide empirical data on the efficiency and effectiveness of simulation-based marksmanship training. Several studies have shown that firer performance is generally poorer in the simulator compared to live-fire [4, 7-9]. In addition, there is considerable variation in the correlation between simulator and live-fire scores, with values of the correlation coefficient (r) ranging from 0.17 (low) to 0.68 (high) [3, 8-11]. For the majority of these studies, low to moderate values of r were found. In these cases, simulator performance was not a useful predictor of live-fire performance and it was not possible to reliably predict live-fire qualification. There appears to be only one example ($r = 0.68$) where it was possible to determine a cut-off score in the simulator which could be used to predict live-fire qualification with reasonable levels of confidence [9].

The above findings have been explained in part by DSTO research, which has found limitations in the simulator component technologies and system design [7, 12]. These include degraded target imagery (relative to targets on outdoor firing ranges) and limitations in the accuracy of the weapon aim-point determination. While unlikely to impact on the use of the system for weapon familiarisation and coaching, these factors may limit the utility of small arms simulators in terms of improving live-fire performance, particularly beyond basic levels of proficiency [12]. This issue is explored further in the following paragraphs, which summarise the outcomes of six studies that have attempted to measure the training effectiveness of marksmanship simulators³.

² This view is based on numerous discussions between the authors and military subject matter experts with considerable experience with both live-fire and simulator marksmanship training. It is also consistent with Army doctrine [13].

³ In four of these studies, the simulator was manufactured by the same company (Meggitt Training Systems Inc.) and is essentially the same device with a different name. In the fifth study, the simulator was manufactured by CUBIC Training Systems; however, the system design and component technologies of the device are essentially the same as the other simulators. Consequently, it is appropriate to compare the outcomes of these studies, as they are not confounded by any major differences in the simulators used.

In a 2001 study with infantry trainees, the Canadian Army assessed the effectiveness of a simulator (Small Arms Trainer (SAT)) for training basic marksmanship skills with the C7A1 rifle [14]. The study compared the outcomes for the Level 3 Personal Weapons Test⁴ (PWT) of four groups of soldiers that received basic marksmanship training using either (1) live-fire training only, (2) simulator training only, (3) simulator training only (with all training repeated), or (4) a combination of simulator and live-fire training. Each group contained approximately 30 soldiers. The training involved conducting the 'Shoot to Live' training program, which consists of ten serials, starting with basic grouping practices at 20 m, progressing to more advanced practices at longer ranges (100 m – 300 m) and culminating in night shooting with illumination (25 m – 100 m).

There was no significant difference between scores on the PWT for the first three groups. However, the fourth group, which received the combination of simulator and live-fire training, achieved significantly higher scores and pass rates for the PWT than the other groups. It was concluded that the blended training method allowed novice trainees (with minimal live-fire experience) to focus on learning the basic firing techniques and gaining familiarity with the weapon system on the simulator whilst conducting simple marksmanship practices. Another significant finding was the impact of marksmanship coaching on the live-fire outcomes. The group which conducted training on the SAT twice was split into two sub-groups, with one group receiving minimal guidance from an instructor and the other group being actively coached and mentored. The group which received coaching achieved higher scores on the PWT, consistent with the simulator having limited effectiveness as a 'black box', which automatically imparts skill through practice (i.e. without the need for instructor intervention or feedback).

In a 2001 study with Australian Army Reservists, James assessed the effectiveness of training aids in the Weapons Training Simulation System (WTSS) [1]⁵. As a secondary objective, the study also measured the transfer of training from the WTSS to the live-fire range for the F88 rifle. Two groups of soldiers conducted a simple 100 m grouping practice on the live-fire range to establish baseline live-fire marksmanship ability. Following this, both groups conducted the same grouping practice in the simulator twice; however, the experimental group (N=9) was provided additional feedback from the simulator training aids, whereas the control group (N=10) was not. Finally, both groups conducted the same 100 m practice on the live-fire range to assess the degree of training transfer from the simulator to live-fire.

The performance of the experimental group improved from first to second attempt in the simulator, whereas there was no significant change in the performance of the control group, consistent with simulator training aids providing useful feedback to the firers. Interestingly, there was a statistically significant decrease in live-fire performance from pre-training to post-training for the experimental group, but a significant increase in performance for the control group. Furthermore, the effect sizes (based on Cohens *d*) were

⁴ The Personal Weapons Test Level 3 requires the firer to engage the target whilst advancing at ranges from 400 down to 25 metres [15].

⁵ The WTSS training aids provide feedback to the firer such as the fall of shot location and the degree of movement of the weapon barrel, which helps firers to correct and refine their marksmanship technique.

medium in these cases ($d = 0.65$ and $d = 0.54$ respectively). Across all firers, there was no significant difference from pre- to post-training live-fire performance. At face-value, these findings suggest that there was a negative transfer of training for the experimental group and a positive transfer of training for the control group. The author noted that this negative transfer may have occurred because the feedback provided by the training aids was not present when the firers moved to the live-fire range, which in turn may have impacted negatively on their performance. While this explanation is plausible, the findings from this study should be interpreted with caution, given the small sample sizes and limited amount of practice trainees were given in the simulator.

In a 2004 study with US Marine Corps recruits, Yates examined the effectiveness of the Indoor Simulated Marksmanship Trainer (ISMT) for training marksmanship fundamentals, compared with traditional methods, for the M16A2 rifle [16]. An experimental group (N=55) conducted three days of classroom training and two days of training in the simulator, followed by a week of live-fire training. No specific details of the marksmanship practices used during simulator training were provided. A control group (N=55) conducted three days of classroom training and two days of dry-fire training⁶, followed by a week of live-fire training. After training, both groups conducted a live-fire qualification shoot, consisting of deliberate and rapid fire at 200, 300 and 500 yards.

There was no significant difference between the qualification scores of the two groups and it was concluded that training on the simulator was equally effective as dry-fire training. However, the author noted that adverse weather may have degraded the performance of the experimental group (which received simulator training) during the qualification test. In addition, both groups conducted one week of live-fire training after the simulator/dry-fire training, prior to qualification. This may have had the effect of reducing any difference between the two groups resulting from differences between simulator training and dry-firing. Consequently, it would have been preferable to compare both groups on live-fire performance immediately following simulator/dry-fire training.

During a 2009 Australian Army training course, training staff examined the effect of additional simulator training on live-fire performance with the M4 rifle [17]. An experimental group conducted the LF6 Application of Fire practice in the simulator for three hours prior to attempting the same qualification task (LF6) on the live-fire range. The control group proceeded straight to live-fire LF6 qualification. The specific details of other marksmanship training undertaken by the two groups are not known, as this information was not reported. The study reported that the experimental group achieved a 100% pass rate at their first or second qualification attempt, whereas the control group achieved a 40% pass rate, consistent with the additional simulator training having a positive impact on subsequent live-fire performance. The training course in the 2009 study was the same as the course in the current study. In addition, the two studies used a similar experimental design, which enables a valid comparison of the outcomes from the two studies.

⁶ Dry firing is a training method involving firing without live rounds and hence there is no weapon recoil or noise from weapon discharge. This method allows the firer to practice holding the weapon correctly, take a sight picture of the target, and practice trigger release and follow-through without using live rounds. The process is observed by trained marksmanship coaches, who provide feedback to the trainees on their technique.

In a 2010 study with US Army cadets, Merlo, Frechette, and Banks examined the transfer of training from the Engagement Skills Trainer⁷ (EST) to live-fire for the M4 rifle [6]. The experimental group (N=952) conducted marksmanship training on the EST prior to being assessed on their live-fire performance. The control group (N=80) consisted of cadets that did not train on the EST but went straight to live-fire. During EST training, cadets fired at a standard M4 zeroing target at 25 m. Training time in the simulator varied between individuals, but did not exceed 30 minutes. During live-fire assessment, cadets were required to fire five rounds at a target consisting of three concentric circles. Firer performance was based on the number of hits within each circle. While the cadets fired up to five iterations at the target, only data from the first two iterations was analysed, as data from subsequent iterations was found to be influenced by the effect of the previous iterations. There was no significant difference between the performance of the control and experimental groups; the amount of time spent in the simulator was also found to have no impact on subsequent live-fire performance. These findings show that the simulator training had no measurable benefit in terms of live-fire performance; however, this finding may be partly explained by the limited amount of time spent training in the simulator.

In a 2012 study with US Navy personnel, Jensen and Woodsen [18] measured the training effectiveness of the ISMT for the 9mm Berretta pistol. In the study, participants were allocated to a control group (N=17) and an experimental group (N=17) based on previous marksmanship experience. Both groups conducted a baseline performance assessment in the simulator; no significant difference between the groups was found. The control group then conducted training in the simulator, but with the weapon recoil disabled, and without any fall-of-shot feedback (i.e. dry firing). The experimental group conducted the same training, but with weapon recoil enabled, and with fall-of-shot information available to trainees. Training for both groups utilised the same marksmanship practices which involved engaging targets at different ranges (3 yards, 7 yards and 15 yards), with no timing restrictions.

After training, both groups conducted a post-training assessment in the simulator; in each case there was a significant improvement from baseline scores⁸. In addition, the experimental group outperformed the control group, consistent with recoil and fall-of-shot feedback resulting in better training outcomes within the simulator (similar to the findings of the James 2001 study [1]). Both groups then conducted a live-fire assessment to measure the degree of transfer from the simulator to live-fire. Measures of performance used in the study were total scores (based on where rounds hit the target) and mean point of impact (MPI) based on the distance from the true target centre and the centre of a group of shots fired at the target. There was no significant difference between the two groups on live-fire performance based on total scores. However, there was a statistically significant difference between the groups based on MPI based on one-tailed significance testing, with medium effect size ($d = 0.74$). This outcome is similar to that found by Yates [16]; that is, the simulator appears to provide similar (or slightly greater) training benefit to dry-firing. However, Jensen's study was based on a 9 mm pistol, whereas the other studies were

⁷ The EST is manufactured by CUBIC Training Systems.

⁸ Both baseline and post-training assessments required firers to engage targets at various ranges (3 yards, 7 yards and 15 yards), under timed conditions and from different firing positions.

based on rifles and involved much longer target distances; it is not clear how the outcomes would generalise from one weapon system to another.

Overall, these studies provide some evidence that marksmanship skills learned in the simulator transfer to the live-fire environment. However, there are no marksmanship studies which have examined the optimum blend of live-fire and simulator training. Consequently, the outcomes of these studies do not add significantly to the anecdotal views regarding the training effectiveness of marksmanship simulators, or provide any guidance on the appropriate mix of simulator and live-fire training.

1.2 The current study

The current study was conducted as part of a broader research program in DSTO which aims to help Army achieve more efficient and effective use of simulation for training. The study was conducted during an Australian Army training course in 2010. During the course, trainees undertook basic marksmanship training on the M4 weapon system using iron sights⁹.

In order to progress through the marksmanship component of the course, trainees were required to pass the LF6 Application of Fire practice on the live-fire range. This practice consists of eight serials and involves firing at targets over different ranges (100, 200, 300 m), as well as firing from different positions at static and moving targets under timed conditions. The practice is described in more detail in Appendix A, together with the other basic marksmanship practices used on the course. The course instructors were seeking to develop a training program using both simulator and live-fire which resulted in faster LF6 qualification and higher marksmanship standards within time and resource constraints [19]. This requirement was one of the drivers for the current study, but also provided an opportunity to address the lack of training evaluation studies in this area.

1.2.1 Training evaluation framework

One of the most commonly used approaches for evaluating training is the Kirkpatrick model [20]. This model proposes training outcomes at four levels: reaction (Level 1), learning (Level 2), behaviour (Level 3) and results (Level 4), as described below. In the current study, we evaluated training outcomes at all four levels.

- Level 1: outcomes include assessment of participants' reaction to the training program. In the current study, we examined trainee feedback on what they liked/disliked about simulator and live-fire training.
- Level 2: outcomes are quantifiable indicators of learning that occur during training. In the current study, we examined changes in trainees' marksmanship scores over the course of training.
- Level 3: outcomes examine the extent to which knowledge and skills gained during training are applied (or transfer) to the job context; this is also known as transfer of

⁹ This is significant because anecdotally, trainees on the course have little prior experience with iron sights, which has implications for their marksmanship performance.

training. In the current study we measured pass rates and changes in marksmanship competency levels.

- Level 4: outcomes provide a measure of the impact that the training has had on organisational goals or performance. In the current study we measured the total training time, the amount of ammunition used and the trainee throughput.

1.2.2 Study aims

The primary aim of the study was to measure the effect of additional LF6 simulator training on live-fire qualification. The hypotheses were as follows:

H0: There will be no differences in LF6 live-fire qualification between groups that receive LF6 simulator training or no simulator training prior to live-fire qualification.

H1: The group that receives LF6 simulator training will have higher LF6 live-fire qualification rates and scores compared with a group that does not receive LF6 simulator training.

The second aim of the study was to investigate predictors of live-fire LF6 qualification. Specifically, we examined the utility of LF6 simulator scores and trainee demographic data as predictors of live-fire LF6 qualification.

The third aim of the study was to compare the outcomes with those of the 2009 study [17]. Specifically, we compared the pass rates between the two studies after two LF6 qualification attempts.

2. Method

2.1 Study approval

The study methods and procedures were approved by an internal human research ethics review committee prior to data collection (Ethics Protocol Number: DSTO LOD 07/10). The study procedures were conducted in accordance with ethical principles and guidelines for the conduct of human research [21].

2.2 Participants

A range of demographic data was collected from the study participants using a paper-based questionnaire. This data was collected as standard practice, in order to characterise the study population, as well as identifying any potential confounds (e.g. poor health). In addition, the demographic data was used to investigate predictors of live-fire performance

and qualification; this is described in Section 2.5.3. A copy of the questionnaire is included in Appendix B.

Thirty-six ADF personnel voluntarily took part in the study. The age of the participants ranged from 21 to 36 years (mean = 26.3 years, SD = 4.1 years). The average length of their military service was 2.6 years (SD = 3.1 years), and the majority of participants (81%) had an Army background.

In terms of marksmanship experience, eight participants (22%) indicated that they had used the M4 weapon prior to the course. Half the participants (50%) reported having experience using iron-sights, mainly with other weapon systems (e.g. pistols, shotguns). In terms of marksmanship ability, 25% of participants rated themselves as "Above Average", 58% rated themselves as "Average", and 17% rated themselves as "Below Average".

All participants reported having shot in either the simulator or the live-fire range in the last 12 months, with the majority (86%) having shot at least twice in both environments during this time. All participants had fired LF6 at least once previously, with the majority (83%) having shot LF6 at least twice within the last 3 months leading up to the study. Overall, the participant's prior marksmanship experience was limited but they were already familiar with the qualification task prior to the study.

All participants reported having good levels of general health at the time of the trial. Two-thirds (64%) of the participants reported having 20/20 vision. Four participants (11%) reported that they wore corrective eyewear. The remaining nine participants reported having non 20/20 vision, but did not report wearing corrective eyewear. As visual acuity testing was not conducted during the study, the standard of their eyesight was not known.

2.3 Study design

The study design was developed in conjunction with the instructional staff. The study team were advised that the following constraints applied:

- a total of five days is available for marksmanship training and LF6 qualification¹⁰
- two days are allocated for LF6 live-fire qualification (to ensure all trainees have a reasonable chance of passing)
- three days are available for practical training
- all trainees must receive the same amount of training¹¹.

The implication for designing the study methodology was that any training intervention conducted by an experimental group would also have to be conducted by the control

¹⁰ During the week prior to marksmanship training, trainees received 5 days of training with the M4 weapon. This included classroom lessons and hands-on training and assessment in the handling, stripping, maintenance, assembly and operation of the M4 weapon system. The training also included lessons on marksmanship.

¹¹ Course instructors indicated that this was necessary to avoid the risk of trainees that did not qualify at LF6 seeking a redress of action, as failure to qualify at LF6 would lead to trainees failing the course [22].

group at some stage during the week allocated to marksmanship training. Consequently, the length of the training intervention was restricted to half a day; any longer than this may have resulted in insufficient time for the control group to qualify at LF6.

Given these constraints, it was agreed with the instructional staff that the study would examine the impact of an additional three LF6 practices in the simulator on subsequent LF6 live-fire qualification. Specifically, the study compared the outcomes for the first three LF6 qualification attempts between the group that received three LF6 practices in the simulator and a group which received no additional simulator training. The reasons for this are as follows.

- Firstly, the time taken to conduct three LF6 simulator practices is close to the maximum amount of training able to be conducted in half a day.
- Secondly, three practices allow the opportunity for feedback and correction, to enable learning to occur.
- Finally, three qualification attempts are considered a reliable basis on which to compare the outcomes for the two groups.

The study design is illustrated in Table 1 below. The study was only a component of the full training program conducted by the two groups; this is described in Section 2.4 and presented in Table 2.

Table 1. Study design.

Group 1 (experimental group)	Initial Training	3 LF6 practices (simulator)	3 LF6 qualification attempts
Group 2 (control group)	Initial Training	No additional training	3 LF6 qualification attempts

In addition, it was agreed with the instructional staff that the study would not include any individual marksmanship coaching, in order to remove a potential confound (i.e. ensuring equivalent levels of coaching/feedback across the two groups). Overall, it was not anticipated that this study would yield an optimum training solution. However, it was expected that the study would provide insights into the benefit provided by simulator training and provide a basis for developing an optimum training methodology as part of future studies.

2.4 Procedure

On the first day, the study team briefed the training staff and participants on the study aim and procedures. Following the brief, the participants completed the demographic questionnaire. The questionnaire requested details regarding participants' age, length of service, prior marksmanship experience, self-rating of marksmanship skill level, general health status, visual acuity, and confidence using the M4 and passing LF6.

The study schedule is outlined in Table 2. Prior to marksmanship training, all trainees were required to zero their weapon on a 25 m firing range. On Day 1 and 2, all participants conducted initial training on the live-fire range and in the simulator. The training content and delivery is at the discretion of the training staff but generally involves conducting a number of basic marksmanship practices as preparation for LF6 qualification. These practices can be conducted in both the simulator and on the live-fire range and are described in more detail in Appendix A¹².

Following training, the participants were split into two groups on the basis of their live-fire scores for the LF1 practice conducted on Day 1. This was achieved by entering the participants' names and corresponding LF1 grouping scores into a spreadsheet, ordering the scores from lowest to highest, and then allocating participants to the two groups on an alternating basis. The resultant mean LF1 scores for each group were 172.2 mm and 172.2 mm, which were not significantly different (mean difference = 0.0 mm, $t = 0.00$, $p = 1.0$) based on an independent samples t-test.

On Day 3, Group 1 (experimental group) received the additional simulator training; specifically, they conducted three LF6 practices in the simulator with no coaching. At the same time, Group 2 (control group) went straight to the live-fire range and conducted three attempts at LF6 qualification. For both the simulator and live-fire practices, there were breaks provided to all participants between LF6 practices in order to reduce the likelihood of fatigue effects on participant's performance. In the afternoon, the experimental group conducted three LF6 qualification attempts on the live-fire range¹³. While the experimental group was conducting LF6 qualification, the control group conducted three LF6 practices in the simulator with no coaching. This was not part of the study design but was simply to ensure that the control group was not disadvantaged and received the same amount of training (as discussed in Section 2.3). While not a specific study aim, this experimental design allowed the effect of live-fire on subsequent LF6 performance in the simulator (i.e. reverse transfer of training) to be measured, by comparing firer performance on the three LF6 simulator practices for the two groups. Note that the LF6 simulator practices did not count towards qualification as this occurs only on the live-fire range. On days 4 and 5, both groups continued to conduct LF6 qualification until all trainees qualified. All trainees conducted at least four qualification attempts¹⁴.

All LF6 scores for the simulator, and for the first three live-fire qualification attempts, including scores for each of the eight serials, were recorded for all participants at the

¹² For the current study, training involved LF1, LF4 and LF5; LF2 and LF3 were not conducted, due to time constraints and range availability.

¹³ Due to time limitations, the experimental group actually completed their third LF6 practice on the live-fire range the following day.

¹⁴ Trainees only need to qualify on LF6 once on the course to progress through the marksmanship training. However, in this study we assessed their level of competency over three attempts; this meant that some trainees qualified more than once. Instructional staff also indicated that it was preferable for trainees to achieve a qualification score more than once in order to confirm their competence at LF6.

completion of each practice¹⁵. The weather conditions were fine with very light winds for all shooting activities conducted on the live-fire range throughout the study. For all practices, the participants wore the Australian Army camouflage pattern uniform and webbing as per the course requirements.

Table 2. Training and qualification schedule conducted by Group 1 and Group 2¹⁶. The study design is enclosed in the bold border.

Time	Group 1: Experimental Group	Group 2: Control Group
pre-training	25 m zeroing	25 m zeroing
Day 1	LF1 (live-fire range) 4-8 attempts	LF1 (live-fire range) 4-8 attempts
	LF1 (simulator) 1 attempt	LF1 (simulator) 1 attempt
Day 2	LF4 (simulator) 1 attempt	LF4 (simulator) 1 attempt
	LF5 (simulator) 1 attempt	LF5 (simulator) 1 attempt
Day 3	LF6 (simulator) 3 attempts	LF6 qualification (live-fire range) 3 attempts
	LF6 qualification (live-fire range) 3 attempts	LF6 (simulator) 3 attempts
Day 4 and 5	LF6 qualification (live-fire range) until all trainees qualify	LF6 qualification (live-fire range) until all trainees qualify

2.5 Measures

2.5.1 LF6 performance

The primary measure of marksmanship performance used in the study was the total number of points scored on the LF6 practice. Five points are allocated for each hit on the target; the highest possible score is 235 points and a pass score is 165 points (i.e. 70% of maximum score); achieving 165 points on the live-fire range results in qualification.

2.5.2 Simulator training effectiveness

A number of different measures were used to assess the effectiveness of the additional simulator training (Level 3):

- The difference in LF6 live-fire qualification rates achieved for each group after each qualification attempt.
- The difference in mean live-fire LF6 scores from the first three qualification attempts on the live-fire range for both groups.

¹⁵ The study team collected live-fire serial scores for the first three qualification attempts only; total scores for the remaining LF6 practices were collected and forwarded to the study team by the instructional staff.

¹⁶ LF1 is a grouping practice in which performance is measured as the extreme spread between the two shots furthest apart in a group of shots. For this practice, lower scores indicate better marksmanship performance. LF4, LF5 and LF6 are application of fire practices, where higher scores indicate better performance. These practices are described in detail in Appendix A.

- Transfer effectiveness ratio (TER) [23-24]. The TER is a measure of the time or number of repetitions in live training (required to reach competency) saved by the use of simulator training, relative to the length of time or number of repetitions of simulator training required to achieve this saving. In this study, the experimental group conducted three repetitions of LF6 in the simulator, hence:

$$TER = \frac{N1-N2}{N3} \text{ Equation 1}$$

where:

- N1 is the mean number of attempts required for the control group (i.e. Group 2) to pass LF6 (no simulation)
 - N2 is the mean number of attempts required for the experimental group (i.e. Group 1) to pass LF6
 - N3 is the number of attempts at LF6 (3) in the simulator for the experimental group.
- Percent transfer (PT) [23-24]. The PT is a measure of the time or number of repetitions in live training (required to reach competency) saved by the use of simulation based training, relative to the length of time or number of repetitions of live training normally required to achieve competency (expressed as a percentage).

$$PT = 100 \times \frac{N1-N2}{N1} \text{ Equation 2}$$

The effect of live-fire on subsequent LF6 performance in the simulator was determined using similar measures (i.e. comparing mean LF6 scores and pass rates in the simulator for both groups). However, as qualification occurs only on the live-range, TER and PT are not relevant measures in this case.

2.5.3 Predictors of LF6 qualification

Linear regression was used to investigate predictors of live-fire qualification. Simple linear regression was used to investigate the utility of simulator LF6 scores in predicting LF6 qualification scores. Multiple linear regression was used to investigate the utility of additional predictors of live-fire LF6 scores. The following variables (collected from the demographic questionnaire) were included in the regression model. Categorical variables (e.g. prior experience with iron sights) which could take only two possible values were excluded.

1. simulator scores (1st attempt)
2. simulator scores (2nd attempt)
3. simulator scores (3rd attempt)
4. mean simulator scores (over 3 attempts)
5. number of times fired in simulator (past 12 months)
6. number of times fired live (past 12 months)
7. marksmanship skill level (1 = below average, 2 = average, 3 = above average)
8. number of times conducted LF6 (prior to study)
9. time since last fired LF6 (months)
10. amount of experience with M4 (months)

11. confidence in using M4 (low = 1, moderate = 2, high = 3)
12. confidence in passing LF6 first time (low = 1, moderate = 2, high = 3)
13. general health during study (1 = well below average, 2 = below average, 3 = average, 4 = good, 5 = excellent).

2.5.4 Number of rounds in training and qualification

The following measures were used as Level 4 outcomes under the Kirkpatrick framework as they relate to the cost and efficiency of training:

- total number of live-rounds expended in training and qualification
- proportion of simulator rounds fired in training
- total number of training rounds fired (simulator plus live)
- average and total number of live-fire qualification attempts.

2.5.5 Trainee reactions

At the conclusion of the study, the participants were asked the following questions regarding the training:

1. How did you find shooting in the simulator as preparation for LF6 on the live-fire range?
2. Did you have any particular issues with specific LF6 serials in the simulator or live-fire range?
3. How did you find shooting with the M4 weapon using iron sights?

The participants' responses to these questions are given in Appendix G and Section 3.4.2.

2.6 Data analysis

All data analysis was conducted using SPSS Version 17.0 [25]. The data was checked for any missing or extreme values that may have unduly affected the outcomes of the data analysis. Normality testing was conducted on the data using the Shapiro-Wilk test. Mean scores and standard deviations were calculated for all LF6 serials and for total LF6 scores. Qualification rates were calculated using 165 points as the cut-off score. The TER and PT were calculated using Equations 1 and 2.

Significance levels for differences in qualification rates between the two groups were determined using a Chi-squared test based on the qualification frequency, with an acceptance (p) value of 0.05; the corresponding effect size was measured using the Phi coefficient. Where data was found to be normally distributed, the mean LF6 scores were compared for the two groups using independent samples t-tests, with an acceptance (p) value of 0.05; the corresponding effect size was measured using Cohens d . Paired samples t-tests were used for within group comparisons of mean LF6 scores. In some cases, data was non-normally distributed; in this case, non-parametric tests were employed (Mann-Whitney test for independent samples; Wilcoxon Signed-rank test for paired samples).

Multiple linear regression was conducted using the 'Forward' entry method. An acceptance (p) value of 0.05 was used for both simple and multiple linear regression.

2.7 Feedback

While there was no specific coaching during the study, some feedback was provided to trainees while conducting LF6 practices in the simulator and on the live-fire range. When conducting LF6 on the live-fire range, at the start of Serial 1, each trainee is allowed two sighting rounds to see their fall-of-shot on the target and adjust their point-of-aim if necessary. In addition, targets fall when hit for all snap and moving target serials, which provides trainees with performance feedback. The only form of coaching provided on the live-fire range was notifying trainees when they had not adopted the correct firing position for a particular serial. When conducting LF6 in the simulator, trainees were able to see their fall-of-shot after each serial, which is the default condition in the simulator. However, the trainees were not provided with any corrective action from training staff based on this information. The training staff merely prompted participants to apply the marksmanship principles during each practice and to adjust their point-of-aim at the target if required.

3. Results

In this section, results are presented in the order to which they relate to the study aims. All references to mean scores in this section refer to the average of three attempts at LF6 qualification unless stated otherwise. Results based on the first three qualification attempts are presented first, followed by results based on all qualification data, in accordance with the study design.

3.1 Effect of additional simulator training on live-fire qualification

3.1.1 Qualification rates and mean scores

The qualification rates for LF6 for the first three attempts are shown in Table 3. After three attempts, 58.3% of all trainees had passed. The group that conducted additional training in the simulator (experimental group) passed more quickly than the group that went straight to the live-fire range (control group). The difference in qualification rates between the two groups was statistically significant after the second attempt ($\chi^2 = 4.43$, $p = 0.04$ ($df = 1$), $\phi = 0.35$). On the basis of pass rates, it can be concluded that the additional simulator training provided a small positive training benefit. Inspection of Table 3 shows that pass rates for the experimental group after the first qualification attempt (i.e. after three simulator and one live-fire LF6) are the same as the pass rates for the control group after two qualification attempts. Pass rates for the experimental group after the second qualification attempt (i.e. after three simulator and two live-fire LF6) are the same as the

pass rates for the control group after three qualification attempts. On this basis, it can be speculated that the three practices in the simulator provided (roughly) the equivalent training benefit as a single qualification attempt on the live-fire range for this sample of trainees.

Table 3. Qualification rates for LF6 on the live-fire range for three attempts.

Group	Qualification rate (%)			Number of passes achieved in three attempts (%)		
	First attempt	Second attempt	Third attempt	Passed once	Passed twice	Passed three times
Experimental group	27.8	50.0	66.7	38.9	5.6	22.2
Control group	22.2	27.8	50.0	22.2	11.1	16.7
All participants	25.0	38.9	58.3	30.6	8.3	19.4

The mean scores for all participants, as well as those for each group are shown in Table 4. The difference between the mean scores over three attempts for the two groups is 8.2 points; this was not statistically significant ($t = 0.91$, $p = 0.37$). This indicates that the impact (either positive or negative) of additional simulator training was too small to be reliably detected using mean scores as the measure of effectiveness.

Table 4. Mean scores for LF6 practices. Numbers in brackets are one standard deviation. The pass score is 165 points and maximum possible score is 235 points.

Group	First attempt	Second attempt	Third attempt	Average of three attempts
Experimental group	147.5 (29.0)	149.2 (27.1)	159.7 (19.7)	152.1 (21.7)
Control group	140.8 (34.1)	139.2 (33.1)	151.7 (38.4)	143.9 (31.5)
All participants	144.2 (31.3)	144.2 (30.2)	155.7 (30.4)	148.0 (27.0)

The mean scores for each LF6 serial are given in Table 5 for all participants, as well as those for each group. Participants performed better at the 100 m serials (Serials 6, 7 and 8) than those at 200 m (Serials 3, 4 and 5) and 300 m (Serials 1 and 2). This is consistent with it being more difficult to hit targets at longer ranges. The difference between the scores for the two groups approached statistical significance for Serial 3 ($U = 101.5$, $z = -1.924$, $p = 0.054$). This outcome suggests that the additional simulator training was effective in terms of subsequent live-fire performance for this serial. However, the difference is only 3.7 points which is less than one hit on the target and is therefore of no practical significance.

Table 5. Mean LF6 live-fire scores for each serial. Numbers in brackets are one standard deviation. HPS is 30 points (Serials 1 – 7) and 25 points (Serial 8).

Group	Serial							
	1 deliberate, 300 m	2 snap, 300 m	3 rapid, 200 m	4 snap, 200 m	5 rapid, 200 m	6 snap, 100 m	7 snap, 100 m	8 moving target
Experimental group	18.3 (6.2)	14.7 (5.7)	18.2 (6.8)	15.6 (5.9)	13.9 (4.7)	26.4 (2.9)	22.9 (4.5)	21.9 (3.3)
Control group	16.6 (6.4)	13.0 (6.3)	14.5 (5.7)	15.5 (7.3)	14.6 (6.1)	26.9 (2.9)	21.7 (4.2)	21.1 (4.5)
All participants	17.5 (6.2)	13.8 (6.0)	16.4 (6.5)	15.6 (6.5)	14.3 (5.4)	26.7 (2.9)	22.3 (4.3)	21.5 (3.9)

The pass rates for all LF6 qualification attempts are shown in Figure 1. Differences in qualification rates observed during the first three attempts are maintained for subsequent attempts; these were statistically significant when comparing qualification rates after four and five attempts ($\chi^2 = 5.63$, $p = 0.02$ (df = 1), $\phi = 0.40$ and $\chi^2 = 4.43$, $p = 0.04$ (df = 1), $\phi = 0.35$, respectively).

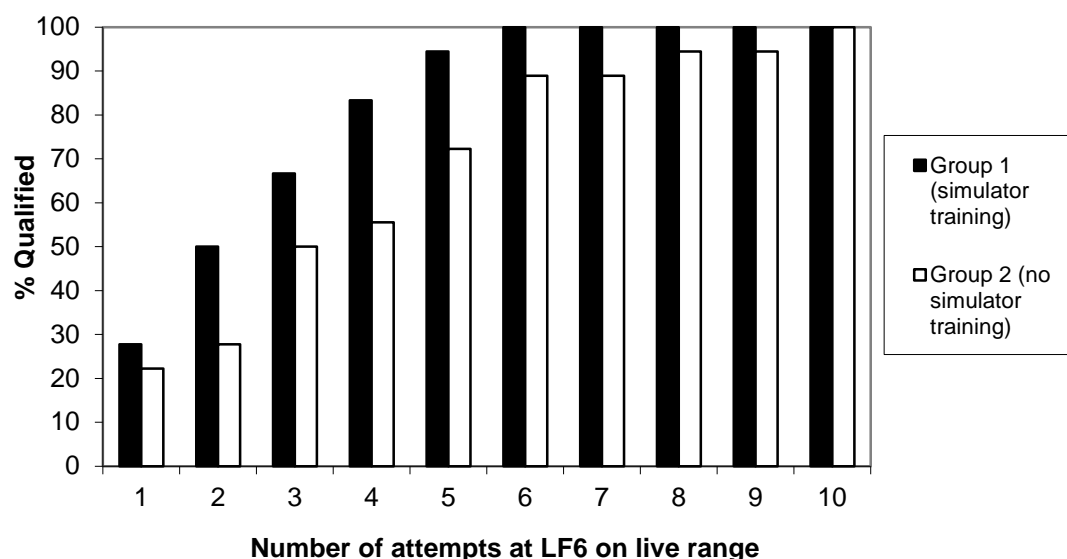


Figure 1. Pass rates for both groups based on LF6 qualification attempts.

The control group conducted three simulator LF6 practices between their third and fourth qualification attempt on the live-fire range. The resulting increase of 12.5 points in the mean scores was not statistically significant ($t = 1.55$, $p = 0.14$). Furthermore, it should be noted that this difference is biased by the performance of one participant, who improved

by 110 points from their third to fourth attempt¹⁷; if the scores for this participant are removed, the difference is reduced to 6.8 points ($t = 1.13$, $p = 0.28$). Indeed, the three LF6 practices conducted in the simulator by the control group resulted in only one additional trainee passing LF6 at the 4th attempt on the live-fire range. Overall, these outcomes indicate that the simulator training conducted by the control group (between their third and fourth qualification attempts) had little impact on subsequent live-fire performance.

3.1.2 Transfer Effectiveness Ratio and Percent Transfer

The final Level 3 measures of effectiveness for the additional simulator training are TER and PT. The mean number of attempts for the experimental group to qualify (N2) was 2.8 (SD = 1.6); the corresponding value for the control group (N1) was 4.1 (SD = 2.6). Values of TER (0.43) and PT (31.5%) were not statistically significant ($U = 115.0$, $z = -1.51$, $p = 0.13$), consistent with any transfer of training from the simulator to live-fire being too small to be reliably detected based on these measures of effectiveness.

It should be remembered that the control group was required to conduct three LF6 practices in the simulator between their third and fourth attempts at LF6 on the live-fire range (in order to ensure both groups conducted the same amount of training). If this training was beneficial, then this would result in an underestimation of N1 and hence an underestimation of TER and PT. However, as noted above, there is evidence to suggest that the simulator training conducted by the control group had little impact on subsequent live-fire performance; hence it is likely that any underestimation of TER and PT is minimal.

3.1.3 Rounds used during training

The number of rounds fired during training by the two groups is shown in Table 6. The experimental group fired 67% more rounds than the control group during training. Given that this additional training yielded only a small benefit in terms of qualification outcomes, this does not represent a good return on investment for Army (i.e. at Level 4). While expending simulator rounds does not incur the same cost as expending live rounds, there is an associated cost in the time taken, and use of resources (using the facility and the simulator operator, use of training staff).

Table 6. Number of simulator and live rounds fired during training

Group	Simulator	Live-fire	Total
Experimental group	5382 (70%)	2268 (30%)	7650
Control group ^{18, 19}	2196 (48%)	2388 (52%)	4584

¹⁷ The next highest increase was 40 points.

¹⁸ When the additional 3 LF6 simulator practices conducted by the control group are taken into account, this figure becomes 69% simulator training (5382 simulator rounds) and 31% live-fire training (2388 live rounds).

¹⁹ The control group conducted slightly more LF1 practices on the live-fire range than the experimental group (on average 5.3 versus 5.0 practices per trainee); this difference was not statistically significant ($U = 145.5$, $z = -0.58$, $p = 0.56$).

3.1.4 Number of live-fire qualification attempts

On average, trainees took 3.4 attempts to pass the LF6 practice. Overall, it took ten attempts over two-and-a-half days for all trainees to qualify (in addition to the three LF6 practices conducted in the simulator). Consequently, the training method used in this study (Table 2) was not particularly effective, and improvements are required. Additional analyses were conducted in order to identify potential training improvements; these are presented in Appendix C. It was found that firers who struggled to qualify had the most difficulty with targets at 200 m and 300 m. In addition, it was found that trainees found it easier to hit targets at longer ranges on the live-fire range than they did in the simulator. The implications of these outcomes are discussed later in Section 4.5, together with options for improving training.

3.2 Predictors of LF6 qualification

The ability to predict marksmanship performance can be useful for identifying those trainees who are likely to qualify and those who may require additional training. In both cases, such information can help inform decisions regarding training scheduling to prevent resource wastage. In this study, a number of measures were investigated for their utility as predictors of LF6 qualification; the results are presented in detail in Appendix D. The correlation between mean live-fire and simulator LF6 scores (over three attempts) for all participants was moderate in size ($r = 0.40$), and was statistically significant ($p = 0.02$)²⁰. Conducting multiple linear regression using additional predictor variables resulted in larger correlation coefficients (up to $r = 0.73$), however this did not result in a reliable prediction of LF6 qualification. In contrast, participants' self-rating of marksmanship skill level showed some utility in predicting qualification. The majority of firers who rated themselves as 'Below Average' shooters failed to pass any of their first four qualification attempts²¹. Conversely, all firers who rated themselves 'Above Average' shooters passed at least two of their first four qualification attempts. These findings are discussed further in Section 4.2.

3.3 A comparison of study outcomes with the 2009 course

As noted in Section 1.1, the outcomes of a similar study conducted during the 2009 course indicated that a group that conducted 3 hours training in the simulator prior to conducting live-fire (experimental group) achieved a 100% qualification rate for LF6 after the first or second attempt; the corresponding rate for the group that went straight to the live-fire range (control group) was 40% [17]. For the current study, the experimental group achieved a pass rate of 50 % after two attempts at LF6; the control group achieved a pass rate of 28% at the same stage. At face-value, these outcomes appear quite different from

²⁰ The correlation coefficient was calculated using the mean LF6 scores over three attempts as this provides a more reliable measure of firer performance.

²¹ Trainees only need to qualify on LF6 once on the course to progress through the marksmanship training. However, in this study we assessed their level of competency over three attempts; this meant that some trainees qualified more than once.

those of the 2009 study. However, an analysis of the data shows that the apparent differences can be explained by:

- differences in the baseline marksmanship ability levels between trainees in the two trials (resulting from differences in training methods between the two courses)
- the use of pass rates as a measure of effectiveness
- small sample sizes.

These analyses are presented in more detail in Appendix E and the outcomes discussed in Section 4.3.

3.4 Additional data

The preceding sections presented the results specifically addressing the study aims, and included an evaluation of training corresponding to levels 3 and 4 of the Kirkpatrick framework. The following sections present additional data, including an assessment of the reverse transfer of training (from live-fire to simulator), as well as training evaluation at Levels 1 and 2 of the Kirkpatrick framework.

3.4.1 Reverse transfer of training

The effect of live-fire LF6 on subsequent simulator performance was measured by comparing pass rates (i.e. scores ≥ 165 points) and mean LF6 scores for the two groups, based on their performance in the simulator (see Section 2.5.2). These results are presented in detail in Appendix F. There was no significant difference in pass rates and mean scores in the simulator between the two groups. This demonstrates that the three LF6 practices conducted by the control group on the live-fire range had no measurable benefit on their subsequent performance in the simulator. That is, there was no detectable reverse transfer of training from live-fire to the simulator for the LF6 practice. Reasons for this outcome are discussed in Section 4.4.

3.4.2 Participant feedback

Participant feedback corresponds to Level 1 in the Kirkpatrick training evaluation framework and provides a qualitative measure of training effectiveness, as well as identifying areas for improvement. The comments made by the participants (and instructional staff) in response to the questions asked at the conclusion of the study are presented in Appendix G and are summarised here. Overall, participants indicated that the simulator provided a useful environment for rehearsing the LF6 task prior to qualification. However, a number of issues were raised as follows:

- Participants reported having difficulty seeing the LF6 targets in the simulator, particularly at longer ranges (e.g. 200 m and 300 m). This observation was consistent with the poorer firer performance in the simulator compared with the live-fire range at these distances.
- Participants noted that the recoil force of the simulated M4 weapon is lower than the recoil force of the real M4 weapon, which could potentially have an impact on the time required to re-establish the point-of-aim after firing. Consequently, this

could lead to a negative training effect when moving from the simulator to the live-fire range.

- Half of the participants felt that conducting six LF6 practices in one day (three in the simulator plus three qualification attempts) was excessive. However, the amount of firing involved was not significantly different from that typically conducted during the course. In addition, there were significant breaks between each LF6; consequently, fatigue is unlikely to have affected the study outcomes.
- Participants indicated that they would have preferred to receive specific feedback about their LF6 performance on the live-fire range. While coaching is not permitted during LF6 qualification, these comments are consistent with the majority of trainees having difficulty qualifying, and hence needing additional assistance.
- All participants agreed that acquiring and engaging targets using iron sights is more difficult than using optical sights, consistent with the slow rate of LF6 qualification.

3.4.3 Changes in marksmanship performance during training

Changes in marksmanship performance during training correspond to Level 2 in the Kirkpatrick training evaluation framework. In this study, Level 2 evaluation of training was conducted by examining changes in marksmanship scores where trainees conducted multiple attempts of the same practice. This occurred for the LF1 practice (conducted on the live-fire range on Day 1 of the study), as well as the LF6 practices conducted in the simulator.

All trainees conducted at least four attempts at LF1 on the live-fire range. For all participants, there was a decrease in mean group size (increase in performance) of 24.5 mm from the first to fourth attempt at LF1, consistent with learning during training. This difference was statistically significant ($z = -1.98$, $p = 0.05$). However, as will be discussed in Section 4.5.2, the LF1 practice is much simpler than the LF6 practice, and is therefore not sufficient preparation for LF6 qualification.

The mean LF6 simulator scores for all participants, as well as those for each group in the simulator are given in Table 11 (Appendix F). For the experimental group, there was an increase of 12.9 points from the first to third attempt. This change was not statistically significant ($z = -1.17$, $p = 0.24$). On this basis, there was no evidence that learning had occurred during the LF6 simulator training.

4. Discussion

This section discusses the results from the study in the context of the study aims. Implications of the findings for marksmanship training are also outlined and discussed, as well as options for future research.

4.1 Training effectiveness

The first aim of the study was to measure the effect of additional LF6 simulator training on live-fire qualification. The primary measure of training effectiveness used in this study was the difference between LF6 qualification rates between the two groups. Using this measure, the results indicated that the group that conducted additional training in the simulator qualified faster than the group that went straight to the live-fire range. However, on the basis of mean LF6 qualification scores, any difference between the two groups was too small to be detected. Overall, it can be concluded that there was a small, positive transfer of training from the simulator to live-fire for the LF6 practice (i.e. Level 3 of the Kirkpatrick framework). A comparison of the pass rates for the two groups indicated that the three LF6 practices in the simulator had roughly the same benefit as one LF6 practice on the live-fire range. Overall, these findings partially support the study hypothesis and are broadly consistent with previous studies examining the training effectiveness of marksmanship simulators [1, 6, 14, 16-18]. That is, there is evidence for limited transfer of training from the simulator to live-fire, and no evidence for negative training.

Ideally, all trainees would qualify first or second attempt, however neither group came close to achieving this outcome. It took ten attempts and two and a half days before all trainees had qualified. Based on this outcome, the training conducted by both groups is not particularly effective. Prior to the first three qualification attempts, the two groups received different training, both in terms of the total number of rounds fired, and the mix of simulator and live-fire training (see Table 6). The three additional LF6 simulator practices conducted by the experimental group equate to 67% more rounds. Given that the experimental group performed only slightly better than the control group over the first three LF6 qualification attempts, this additional training represents a poor return on investment for Army. Potential reasons for these findings, together with some recommendations regarding areas for improvement to the marksmanship training, are discussed in Section 4.5.

4.2 Predictors of LF6 qualification

The second aim of this study was to investigate predictors of LF6 qualification. Ideally, training staff would be able to use simulator scores to decide whether trainees were ready to proceed to LF6 qualification, and avoid wasting live ammunition on trainees who were likely to take multiple attempts to pass. However, the correlation between simulator and live-fire performance ($r = 0.4$) was too small to achieve this outcome; it was not possible to set a cut-off score in the simulator which would allow reliable discrimination between those who were likely to qualify and those who were not. An additional implication of this finding is that the simulator should not be used to replace live-fire for marksmanship assessment.

Similar outcomes have been found in other studies which compared firer performance in the two environments, with correlation coefficients generally low to moderate [3, 8, 10-11]. The observed magnitude of r is likely to be due to three factors: (1) the particular

marksmanship task being conducted (2) variance in firer performance across trials and (3) differences between the simulator and live-fire environments. In this study, a repeated measures method was employed with simulator and live-fire scores being averaged over three attempts. This will reduce the effect of firer variance across trials and should result in higher values of r than for a single measurement. By way of comparison, the correlations between LF6 practices conducted on the live-fire range (e.g. correlation between live-fire 1st attempt at LF6 and live-fire 2nd attempt at LF6) and those between LF6 practices conducted in the simulator (e.g. correlation between simulator 1st attempt at LF6 and simulator 2nd attempt at LF6) were all higher than 0.4²². Consequently, the correlation ($r = 0.4$) observed between simulator and live-fire LF6 scores is unlikely to be due to firer variance, and is more likely to reflect differences between the simulator and live-fire environments for the LF6 task (e.g. target imagery, weapon recoil). These differences are discussed further in Section 4.5.1. The implication here is that the LF6 task in the simulator is similar, but not equivalent, to the LF6 task on the live-fire range.

Interestingly, self-ratings of marksmanship ability showed greater potential than simulator scores in predicting LF6 qualification. While it is not recommended that trainees be allowed to proceed straight to qualification on the basis of self-report data, such data could be used on future courses to identify trainees requiring additional assistance in the early stages of training.

4.3 Comparison with 2009 study outcomes

The third aim of the study was to compare the outcomes with those of the 2009 course [17]. At face-value, the outcomes of the current study suggest that the benefit of the additional simulator training was less in the current study than in the 2009 study. However, as shown in Appendix E, these differences can be explained by differences in the baseline marksmanship ability levels of trainees between the two studies (prior to conducting LF6 training in the simulator), and the use of pass rates as a measure of effectiveness (in conjunction with small sample sizes).

Differences in baseline marksmanship ability between the 2009 and 2010 studies could be due to differences in trainee characteristics²³, but are more likely to be a result of differences in the overall training method used in the two studies. Potential differences include the amount of marksmanship coaching, the specific practices conducted (prior to the additional LF6 simulator training), and the amount of live-fire training. Without knowing the specific training conducted in the 2009 study, it is not possible to speculate further.

²² Live-fire: $r = 0.65$, $p < 0.001$ (1st vs. 2nd attempt); $r = 0.68$, $p < 0.001$ (1st vs 3rd attempt); $r = 0.65$, $p < 0.001$ (2nd vs 3rd attempt). Simulator: $r = 0.61$, $p < 0.001$ (1st vs 2nd attempt); $r = 0.45$, $p < 0.01$ (1st vs 3rd attempt); $r = 0.50$, $p < 0.01$ (2nd vs 3rd attempt).

²³ There is no demographic data available for trainees in the 2009 study so we cannot compare demographic variables across the two studies.

4.4 Reverse transfer of training

As shown in Section 3.4.1 and Appendix F, there was no evidence to suggest that conducting LF6 on the live-fire range had any impact on subsequent LF6 performance in the simulator. Given that differences between the simulator and live-fire ranges may have limited the transfer of training from the simulator to live-fire (Section 4.5.1), it is likely that these differences would also impact on the reverse transfer of training. Furthermore, trainees in the experimental group conducted the LF6 training in the simulator as preparation for qualification; trainees in the control group conducted the simulator training only to ensure both groups received equal training after having already conducted three attempts at qualification. The 50% of trainees in the control group that failed to qualify after three attempts may have some incentive to make use of this training opportunity; the other 50% of trainees that had already qualified may have had limited incentive to perform well in the simulator.

4.5 Potential reasons for study findings and possible future training options

As discussed in Section 4.1, the additional simulator training conducted by the experimental group, as well as the overall training conducted by both groups, failed to lead to satisfactory qualification rates (e.g. qualify first or second attempt). The following sections outline possible reasons for these findings, together with a number of options for future studies aimed at improving training outcomes²⁴. While these options may appear to require additional training and resources, if they proved effective, they would result in less time and resources being spent qualifying on LF6.

4.5.1 Limitations of the simulator environment

One reason for the limited benefit resulting from the additional simulator training could be the difference between the target characteristics in the simulator compared with those on the live-fire range. It has been previously reported that the target brightness and contrast in the simulator are significantly lower than on the live-fire range under daytime ambient conditions [7-8]. This has implications for firers when attempting to acquire and engage targets, particularly at longer ranges, with 'snap' serials and when using iron sights. If the firer has difficulty acquiring the target, it is likely that this will limit the amount of training benefit possible. This is consistent with the lower scores in the simulator compared with live-fire (Appendix C), the poorer performance at 200 m and 300 m serials (Appendix C) and the moderate correlation between simulator and live-fire scores (Appendix D). It is also consistent with participants' comments (Section 3.4.2 and Appendix G) and findings from previous studies [8]²⁵.

²⁴ Several of these options were subsequently investigated as part of a trial on a subsequent course; the results of this trial are reported elsewhere [26].

²⁵ DSTO research has also found that the hit-detection accuracy in marksmanship simulators is less than on the live-fire range [12]. However, the level of accuracy is high relative to the size of the targets employed in LF6 and is therefore not likely to be a significant problem.

The simplest method for improving target image brightness and contrast would be to change the appearance of the target; for example, by using a plain white or orange target. Most marksmanship simulators have an authoring function which would readily allow such a solution to be implemented²⁶.

As noted in Appendix G, the lower weapon recoil in the simulator compared with the real weapon may be an additional factor that limits the effectiveness of training in the simulator. While the lower recoil is likely to make it easier to engage targets in the simulator, this may actually provide a negative training effect when using the real weapon. There is no obvious safe solution to address this issue. Should the improvements to the target imagery result in better training outcomes then it may not be necessary to modify the recoil.

4.5.2 Training progression

Prior to the LF6 practices in the simulator, the trainees conducted several LF1 practices on the live-fire range, and conducted the LF4 and LF5 practices once each in the simulator (Table 2). The LF1 practice is a 100 m grouping practice fired from the prone unsupported position and is consequently much simpler than LF6, which involves engaging targets up to 300 m from various firing positions. There are some similarities between the serials in LF6 and those in LF4 and LF5, however, these practices were conducted only once in the simulator. If the LF6 practices conducted in the simulator are included, the training did provide a systematic progression towards live LF6 qualification (i.e. the crawl-walk-run approach [27]). However this appears to have been confounded by the limitations in the simulator environment identified above; overall, there was a lack of live-fire training at longer ranges. The net impact is that the less skilled firers (i.e. those that failed to pass any of their first three qualification attempts) had particular difficulty at engaging targets at 200 m and 300 m (Appendix C). Consequently, the training did not provide the necessary progression from simple to more difficult tasks required as preparation for LF6 qualification.

The LF6 practice contains two serials at 300 m, three serials at 200 m and three serials at 100 m; the practice also includes four snap serials. The LF4 practice has serials at 100 m and 200 m; there are no serials at 300 m and no snap serials. The LF5 practice involves only moving targets at 100 m. Given that trainees had the most problems with targets at 200 m and 300 m during qualification, then the LF4 and LF5 practices alone may not provide sufficient preparation for the LF6 practice. This view is supported by the fact that trainees performed reasonably well at LF4 and LF5 in the simulator prior to the study (pass rates were 71% and 84%, respectively²⁷). Consequently, future courses could focus on engaging targets at 200 m and 300 m. This could involve a modified LF6 practice where trainees start with grouping serials from the prone unsupported position with no timing constraints before progressing to rapid and snap serials, as well as firing from other positions. The LF3

²⁶ DSTO has subsequently received approval from the manufacturer of the simulator to implement the proposed solution. Without such approval, it would have been necessary to pay the manufacturer to perform the changes.

²⁷ This data was provided to the study team by the course instructional staff.

practice (which involves deliberate and rapid serials from the prone unsupported position at ranges of 200 m and 300 m) may meet some of these requirements.

4.5.3 M4 and iron sights

The difficulty in using iron sights is another factor that could explain the study findings. As noted previously, most of the participants had limited experience with the M4 weapon and iron sights and were more experienced with optical sighting systems. Use of the iron sight requires different aiming and sighting techniques to those employed with optical sighting systems. As noted by the participants (Section 3.4.2, Appendix G), it is generally accepted that it is easier to engage targets with optical sights compared with iron sights (especially at longer ranges). In particular, for static targets such as those on live-fire ranges, acquisition times are likely to be shorter with an optical sight. In addition, the current basic marksmanship practices in the Australian Army (i.e. LF1 to LF6) have been designed primarily for the Steyr optical sighting system.

The M4 also requires different holding techniques to the Steyr, and the position and hold of the weapon is changed slightly for different target ranges and firing positions. Although trainees received lessons on holding, aiming and firing the M4 as part of the course, trainees had a limited chance to become familiar with the M4 prior to attempting LF6.

The trainee's lack of experience with the M4 weapon system and iron sight could potentially be addressed by conducting dry firing, as well as implementing some practices specific to this weapon system. Army doctrine notes that dry firing is an important component of marksmanship training [13], and would be particularly useful for greater familiarisation with the M4 and iron sights. Additional options could include commencing training by conducting grouping practices at 25 m first, then at 100 m in order to develop confidence by conducting a simple task in the early stages of the training. Once this has occurred, training could focus on conducting practices that progress to LF6 as outlined in Section 4.5.2 above.

Given that trainees are generally used to firing with optical sights, another option is to commence M4 training using an optical sight. After trainees had become sufficiently familiar with this system, they could then remove the optical sight and use the iron sight. Alternatively, the requirement to qualify using iron sights could be changed to allow qualification using optical sights; however, decision-makers would need to weigh up the impact on marksmanship capability levels before implementing such a policy change.

4.5.4 Coaching and feedback

Army doctrine notes that effective coaching at all stages of training is essential to improve shooting standards [13]; consequently, the absence of individual coaching is likely to be a factor in explaining the study findings. One reason for the poor performance at LF6 qualification may be that trainees were not applying the basic marksmanship principles correctly during the study. Alternatively, they may simply have not been using the iron sight correctly, due to a lack of experience. Either way, the only way to address these issues is with marksmanship coaching.

Fall-of-shot feedback was available in the simulator and live-fire range; however based on the LF6 qualification outcomes, this does not appear to have been of benefit to the trainees. An inspection of the fall-of-shot pattern from the live-fire qualification data showed that there were a few instances where firers appeared to be systematically aiming off target. As this was a qualification task, this information was only available to trainees at the end of the practice. However, trainees did have the opportunity to adjust their point-of-aim using the sighting rounds fired in Serial 1. Overall, low scores appeared to correspond to a significant spread in shot location, consistent with poor application of marksmanship techniques; this could not have been addressed without coaching.

When conducting LF6 in the simulator, trainees were able to see their fall-of-shot after each serial, but were not provided with any corrective action from training staff based on this information. Research has shown that trainee learning is facilitated when they receive specific feedback about processes (e.g. marksmanship technique) and outcomes (e.g. LF6 scores, fall-of-shot pattern) associated with the task being conducted [28]. In this trial, the feedback provided to trainees was mostly outcome-based. Given that the resultant effect of additional simulator training was limited, it is possible that a greater degree of coaching would have resulted in greater training effectiveness in terms of subsequent LF6 qualification. It has previously been found that transfer of marksmanship skills from the simulator to live-fire is greater when coaching is employed [14]. However, in the specific case of conducting LF6 with iron sights, the limitations with the simulator target imagery may need to be addressed to maximise the benefit of coaching.

4.5.5 Tailoring training to trainee requirements

In any training program where the aim is to ensure all personnel pass, training throughput will be limited by the slowest trainees. Out of the thirty six participants, nine passed one of their first four attempts, and eleven failed to pass any of their first four attempts. Targeting these two groups is where the greatest efficiencies can be achieved because these trainees consume the most time and resources. Individuals requiring additional training should be identified early in (or prior to) the course; they could then receive additional training and/or coaching. If practical, the more skilled firers could progress more quickly to LF6 without this additional assistance²⁸.

As noted in Section 4.2, self-ratings of marksmanship ability were reasonable predictors of LF6 qualification. If additional data was collected prior to the course (e.g. trainees most recent live-fire scores), this information could help to (1) identify trainees likely to have difficulty qualifying at LF6 and (2) assist with determining resource requirements for the course. In theory, trainees should record such information in a shooters log.

²⁸ The authors acknowledge that there needs to be an appropriate balance between providing adequate training and not 'spoon-feeding' the trainees (i.e., providing trainees with too much feedback/coaching). It is important that the more skilled firers are still given enough feedback in order to support their progress during training.

4.6 Study limitations

The main limitation in this study was the small sample size, with only 18 participants in each group. In addition, the course is only run annually, which means there is infrequent opportunity to build upon the outcomes of the current study and examine the training options outlined in Section 4.5 above.

The other main limitation was the requirement to fit the study design within the constraints of the training course, in particular, the requirement for both experimental and control group to conduct the LF6 simulator training. While this had minimal impact on the study outcomes, it constrained the options for the study design.

5. Conclusion and recommendations

The aim of the study was to measure the effect of additional LF6 simulator training on live-fire qualification. The main finding of this study was that additional LF6 training in the simulator provided a small, positive benefit in terms of subsequent LF6 qualification. Specifically, three LF6 practices in the simulator were of similar effectiveness to one LF6 practice on the live-fire range; this outcome partially supports the study hypothesis. The findings are broadly consistent with previous studies, which have found evidence of positive transfer of training from the simulator to live-fire.

Overall, however, the additional simulator training provided a poor return on investment in terms of the subsequent qualification rates, with the majority of trainees in both groups requiring numerous attempts to qualify. Consequently, the simulator training, in conjunction with the overall training method used on the course was not satisfactory. The most likely reasons for this outcome include limitations in the simulator target imagery, the lack of experience of the trainees with the M4 weapon and iron sights, and the limited coaching/feedback provided to trainees during the study. The clear message here is that many factors contribute to effective training beyond the utility of the specific training environment (i.e. simulation or live-fire). Furthermore, unless consideration is given to these factors, it is unlikely that satisfactory training outcomes will be achieved and questions regarding the effectiveness of the simulator, and the optimum blend of live-fire and simulator training are secondary.

Additional studies will therefore be required in order to develop a more effective marksmanship training methodology for live-fire LF6 qualification with the M4/iron sights which uses a combination of simulation and live-fire. The optimum solution is likely to be one that is tailored to accommodate trainees with a wide range of marksmanship ability and ensures trainees follow a logical progression from simpler to more difficult tasks, in line with marksmanship doctrine [13]. Accordingly, it is recommended that the following options are investigated in future studies:

- Improving the brightness and contrast of the target images in the simulator and evaluating any impact on subsequent training effectiveness (Section 4.5.1).

- Designing, implementing and evaluating marksmanship practices aimed at improving trainee familiarisation and confidence with the M4 weapon system and iron sights, which follow a logical progression from simpler to more difficult tasks (Section 4.5.2 and 4.5.3). This could also include (initially) using the M4 with an optical sight.
- Providing individual marksmanship coaching to trainees to ensure correct application of marksmanship principles and M4 weapon handling (Section 4.5.4).
- Collecting data on trainee marksmanship ability prior to training courses to identify trainees likely to require additional assistance (Section 4.5.5). This could be done using a simple self-assessment of ability and/or objective data on each trainee's marksmanship performance (e.g. previous LF6 scores from the shooters log).

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Appendix A: Description of marksmanship practices

The range practices for basic marksmanship proficiency (in order of increasing difficulty) are:

- a. LF1: the grouping practice (100 m)
- b. LF2: The Zeroing Practice (100 m)
- c. LF3: The Application of Fire Prone Practice (200 to 300 m)
- d. LF4: the Application of Fire (Other Positions) Practice
- e. LF5: The Moving Target Practice
- f. LF6: The Application of Fire Practice.

LF1 – LF5 are described briefly below; LF6 is described in detail in Table 7. The targets used for the LF6 practice are shown in Figure 2.

- LF1: the grouping practice 100 m. This involves firing 4 x 5 round groups from the prone unsupported position at a static target at 100 m. The aim of the practice is to teach shot grouping ability, i.e. precision.
- LF2: the zeroing practice 100 m. This involves firing 4 x 5 round groups from the prone unsupported position at a static target at 100 m. The aim of the practice is to confirm weapon zero and make adjustments to the weapon sight as required.
- LF3: the application of fire prone practice 200 to 300 m. This involves engaging targets at distances of 200 m and 300 m from the prone unsupported position, using the deliberate and rapid techniques. The aim of the practice is to teach the application of fire to the maximum effective range of the weapon.
- LF4: the application of fire (other positions) practice- 100 to 200 m. This involves engaging targets at distances of 100 m and 200 m from sitting, kneeling or squatting and standing positions both supported and unsupported, using the deliberate and rapid techniques. The aim of the practice is teach the application of fire from different positions.
- LF5: the moving target practice. This involves engaging moving targets at 100 m; with targets moving left or right, and at different speeds. The aim of the practice is to teach the appropriate technique for engaging moving targets at ranges up to 100 m.
- LF6: the application of fire practice. This involves engaging static targets at distances of 100 m, 200 m and 300 m and moving targets at 100 m from all conventional firing positions, using deliberate, rapid and snap techniques.



Figure 2. The Figure 11 target (left) and Figure 12 target (right).

Table 7. The LF6 practice. Scoring is five points per hit on target. HPS = highest possible score.

Serial	Type	Range (m)	Rounds	Target Type	Firing Position	Description and Timings	HPS
1	Deliberate Timed	300	8	Figure 11	Standing Supported (Weapon Pit)	Two sighting rounds (in firers own time) are fired at a Figure 11 target followed by six rounds to score in two minutes.	30
2	Snap	300	6	Figure 11	Prone Unsupported	One round is fired at each of six exposures of a Figure 11 target. Targets are exposed for 3 seconds with an interval of 5 to 10 seconds between exposures.	30
3	Rapid	200	6	Figure 12	Sitting Supported	6 rounds are fired at one 24 second exposure of a Figure 12 target.	30
4	Snap	200	6	Figure 12	Kneeling or Squatting Supported	1 round is fired at each of six exposures of a Figure 12 target. Targets are exposed for 3 seconds with an interval of 5 to 10 seconds between exposures.	30
5	Rapid	200	6	Figure 12	Sitting Unsupported	6 rounds are fired at one 30 second exposure of a Figure 12 target.	30
6	Snap	100	6	Figure 11	Kneeling or Squatting Unsupported	1 round is fired at each of six exposures of a Figure 11 target. Targets are exposed for 3 seconds with an interval of 5 to 10 seconds between exposures.	30
7	Snap	100	6	Figure 11	Standing Unsupported then Kneeling or Squatting Unsupported	1 round is fired at each of six exposures of a Figure 11 target. Targets come in 3 sets of 2 targets; in each set targets are engaged from a different position. Target exposures are for 3 seconds, with a 3 second interval between sets.	30
8	Moving Target	100	15	Figure 11	Kneeling or Squatting Supported	A maximum of 3 rounds are fired at each of 5 exposures of a moving Figure 11 target. Target speeds are random (1, 2 or 3 ms ⁻¹). Targets move either right to left or left to right over 10 metres.	25
Total			59				235

Appendix B: Demographic questionnaire

Rank..... Age.....

First Name..... Surname.....

Previous Unit..... Years of ADF Service.....

Branch of Service..... Corp/Mustering.....

1. How many times have you fired a rifle in the past 12 months (including WTSS and live-fire)?
2. Prior to the course, how would you have rated your marksmanship skill level?
 - ☐ Below average (do not consistently pass Annual Weapons Test first time)
 - ☐ Average (usually pass Annual Weapons Test first time)
 - ☐ Above average (always pass Annual Weapons Test first time and score well below pass mark)
3. How many times have you conducted the LF6 practice in your career?
4. When was last time you shot LF6? Specify month and year.
5. Prior to this course, have you ever used the M4 weapon? ☐ Yes ☐ No
 - a. If yes, how much experience (in months or years) have you had with the M4 weapon?
6. Prior to this course, have you ever used a weapon with iron sights? ☐ Yes ☐ No
 - a. If yes, please specify weapon system.....
 - b. How much experience have you had with that weapon (in months or years)?
7. Based on your current level of training, how would you rate your confidence in using the M4?
 - ☐ Low ☐ Moderate ☐ High
8. How confident are you of passing LF6 first time with the M4 weapon?
 - ☐ Low ☐ Moderate ☐ High
9. Do you wear corrective glasses/eyewear? ☐ Yes ☐ No
10. Do you have 20/20 vision? ☐ Yes ☐ No
11. How would you rate your general health today? (please tick)
 - ☐ Well Below Average
 - ☐ Below Average
 - ☐ Average
 - ☐ Good
 - ☐ Excellent
12. Are there any factors (e.g. illness, injury) that you believe may affect your marksmanship performance in this trial?
 - ☐ Yes → please describe:
 - ☐ No

Appendix C: Analysis of marksmanship performance data to identify potential training improvements

The following sections present the results of an analysis of marksmanship performance data from the study that was conducted to help identify potential training improvements.

C.1. LF6 serial scores based on live-fire qualification rates

The mean scores for each live-fire LF6 serial are shown in Figure 3; participants were classified according to the number of times they passed their first three attempts at LF6 on the live-fire range (i.e. none, one, two/three²⁹). Values are shown as a percentage of the maximum possible score achievable for each serial. Participants performed better at 100 m serials than at 200 m and 300 m. The differences between firers that passed two or three attempts and firers that did not pass on any attempt are greatest for Serial 1 (mean difference = 7.9, $t = 3.50$, $p = 0.002$, $d = 1.41$), Serial 3 (mean difference = 10.3, $t = 6.03$, $p < 0.001$, $d = 2.36$), Serial 4 (mean difference = 9.5, $t = 4.41$, $p < 0.001$, $d = 1.72$) and Serial 5 (mean difference = 8.3, $t = 5.48$, $p < 0.001$, $d = 2.11$). All participants performed poorly at Serial 2; a snap serial at 300 m. While an improvement in firer performance for all serials would lead to faster LF6 qualification, these results suggest that marksmanship training should focus on tasks similar to Serials 1, 3, 4 and 5, where the poorer firers struggled the most; this is discussed further in Section 4.5.2.

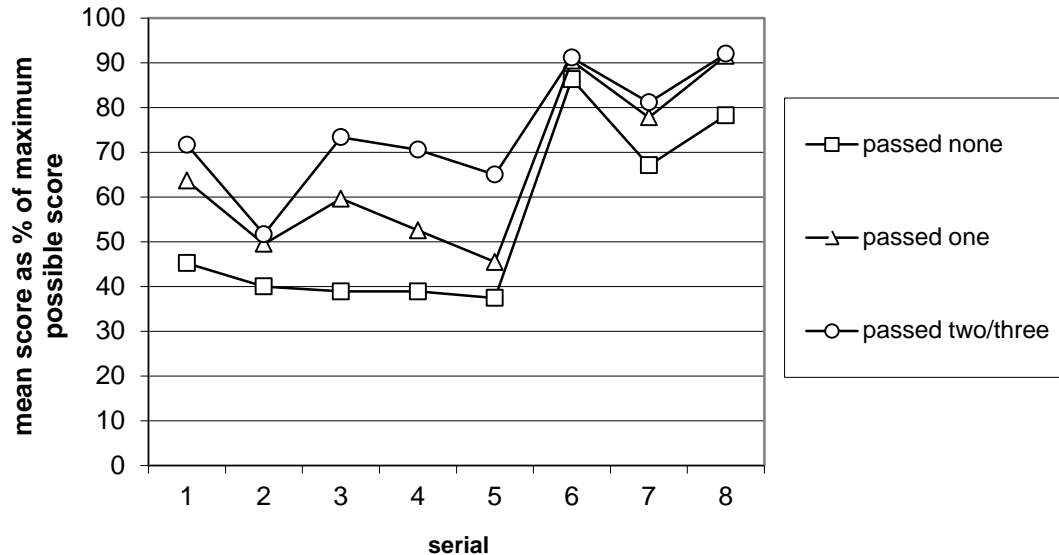


Figure 3. Mean score for each serial for the first three attempts at LF6 on the live-fire range as a percentage of the maximum possible score. Participants are classified according to the number of times they achieved a qualification score (i.e. ≥ 165 points).

²⁹ Scores for firers who passed two or three times in their first three qualification attempts were combined due to small sample sizes.

C.2. Differences between simulator and live-fire scores

The mean scores for all participants for serials at 100 m, 200 m and 300 m, and for the LF6 practice in the simulator and on the live-fire range are shown in Table 8. The mean LF6 scores on the live-fire range were higher than those in the simulator, but the difference was not statistically significant ($t = 1.72$, $p = 0.09$). The differences between simulator and live-fire mean scores increase with target range. These differences were statistically significant for 300 m ($t = 2.57$, $p = 0.01$, $d = 1.12$) and 200 m ($z = -1.96$, $p = 0.05$) but not at 100 m ($t = 1.21$, $p = 0.24$). Overall, the data suggests that participants found it easier to hit targets at longer ranges on the live-fire range than they did in the simulator³⁰. This is supported by participants' feedback (see Appendix G), which indicated that they had difficulty seeing the LF6 targets in the simulator, particularly when targets were at 200 m and 300 m. Consequently, more effective training could potentially be achieved by improving the target visibility in the simulator. This is discussed further in Section 4.5.1.

Table 8. Mean scores for 100 m, 200 m, and 300 m serials in the simulator and live-fire range. Numbers in brackets are one standard deviation.

Serials	Range (m)	Simulator	Live-fire range	Difference
6, 7 and 8	100	22.8 (2.6)	23.5 (2.7)	0.7
3, 4 and 5	200	13.8 (4.3)	15.4 (5.0)	1.6
1 and 2	300	13.1 (4.5)	15.6 (5.0)	2.5
All	100, 200, 300	137.5	148.0	10.5

³⁰ This analysis is based on all participants' scores so does not take into account the order in which trainees shot in the simulator and on the live range. However, similar results were obtained when the analysis was conducted for the two groups separately.

Appendix D: Predictors of live-fire performance

D.1. Correlation between predictor variables and live-fire LF6 scores

In terms of assessing readiness for live-fire qualification, the most useful predictor would be the scores for the final LF6 practice in the simulator. The correlation between the LF6 scores for the third attempt in the simulator and the scores for the first, second and third qualification attempts were $r = 0.06$, $r = 0.48$ and $r = 0.16$, respectively. The corresponding significance values were $p = 0.72$, $p = 0.003$ and $p = 0.36$, respectively. These levels of correlation are too low to allow useful prediction of live-fire performance. Similar values for the correlation coefficients have been found in previous studies comparing marksmanship performance in the two environments [3, 8, 10-11].

There was considerable variation in the correlation between the scores for the final simulator practice and the first, second and third qualification attempts. One possible reason for this is firer variance; a single practice may not be an accurate reflection of firer ability. In order to reduce the possible effect of firer variance, the mean scores over three attempts in the simulator and on the live-fire range were used. The correlation between mean LF6 live-fire and simulator scores for all participants was moderate in size ($r = 0.40$), and was statistically significant ($p = 0.02$)³¹. This level of correlation is also too low to provide useful prediction of live-fire performance.

Given this outcome, additional predictors of live-fire performance were investigated using multiple linear regression (see Section 2.5.3). The dependent variables were the LF6 scores for first and second qualification attempts. The outcomes from the regression are summarised below in Table 9. The use of a multiple regression model results in larger correlation coefficients, which indicated that this set of variables is a reasonable predictor of live fire performance. However, it is still not possible to select a cut-off value for the independent variable which results in reliable prediction of qualification. Furthermore, multiple linear regression is not a very practical tool for training staff to assess readiness for live-fire qualification.

Table 9. Predictors of live-fire performance for multiple linear regression

Dependent variable	Predictor variables	r	p
LF6 scores (1 st qualification attempt)	number of times fired live (past 12 months), marksmanship skill level	0.66	< 0.001
LF6 scores (2 nd qualification attempt)	mean simulator scores (over 3 attempts), marksmanship skill level	0.73	< 0.001

³¹ Correlations between live-fire and simulator serial scores were not conducted due to the narrow range of scores observed for some serials.

D.2. Predictors of live-fire qualification

The linear regression model is a predictor of live-fire performance, where the dependent variable is the live-fire LF6 scores (i.e. effectively a continuous variable). A more direct measure of readiness for qualification would be to predict the likelihood of live-fire qualification, where the dependent variable is whether or not the firer qualified (i.e. a categorical variable). In this case, logistic regression can be used to predict the likelihood of qualification; however, due to the small sample size, logistic regression was not conducted on the data. Instead, the relationship between skill-level (which was found to be the strongest predictor in the linear regression model) and qualification outcomes was measured qualitatively by inspection of the data.

Table 10 shows the number of times each trainee achieved a qualifying score (i.e. ≥ 165 points) over four attempts at LF6 on the live-fire range for each category of skill level. It is noteworthy that all trainees who rated their skill level as above average passed at least two out of their first four attempts at LF6; none failed. Conversely, for those trainees who rated their marksmanship skill level as below average, only one trainee achieved a pass score³². This analysis provides additional evidence for the utility of participants' self-rating of marksmanship skill level in discriminating between good and poor performance at LF6 on the live-fire range. The implications of these findings are discussed in Section 4.2 and 4.5.5.

Table 10. Breakdown of live-fire passes for each self-rated skill level. Numbers in brackets are percentages.

Skill level	N	Passed none of four	Passed one of four	Passed two of four	Passed three of four	Passed four of four
Below Average	6	5 (83.3)	0 (0.0)	1 (16.7)	0 (0.0)	0 (0.0)
Average	21	6 (28.6)	9 (42.9)	2 (9.5)	2 (9.5)	2 (9.5)
Above Average	9	0 (0.0)	0 (0.0)	4 (44.4)	1 (11.1)	4 (44.4)

³² Significance testing was not conducted on this sample due to the low cell count for some categories. More data would be required to validate the utility of self-ratings for predicting live-fire performance.

Appendix E: Analysis of 2009 and 2010 study outcomes

The outcomes of the 2009 study (Section 1.1) indicated that a group that conducted 3 hours training in the simulator prior to conducting live-fire (experimental group) achieved 100% LF6 qualification after the first or second attempt; the corresponding rate for the group that went straight to the live-fire range (control group) was 40% [17]. For the current study, the experimental group achieved a pass rate of 50 % after two attempts at LF6 qualification; the control group achieved a pass rate of 28% at the same stage. These differences can be explained (in part) by (1) differences in the baseline marksmanship ability levels between trainees in the two studies, (2) the use of pass rates as a measure of effectiveness and (3) small sample sizes.

For any population where the probability distribution for trainee performance follows a normal distribution (or any similar symmetrical distribution), the impact of training (i.e. an increase in mean performance scores) on pass rates is not linear. Rather, it will be greatest where the mean score of the population is equal to the qualification score, and lowest where the mean score is much lower or higher than the qualification score. This is intuitive; if the majority of trainees are well below the qualification standard, even a moderate increase in performance scores may not lift many trainees above the qualification standard; hence training will have little impact on pass rates. Similarly, if the majority of trainees are already above the passing standard, their level of performance is unlikely to increase much after training. In this case, training will also have a minimal impact on pass rates as the majority would already qualify without training.

In the current study, prior to attempting LF6 qualification, trainees in the control group were well below the required standard of 165 points such that only 22% passed after one attempt and 28% after two attempts. In contrast, in the 2009 trial, 40% of trainees in the control group passed first or second attempt consistent with their standard being closer to the qualification score. Assuming both groups in the 2009 study were of similar standard, this means that even if the additional simulator training led to a small increase in LF6 scores, this could still have a marked effect on pass rates for the experimental group. This is illustrated in Figure 4, which shows the qualification rates for the current study after adding 5 points to the LF6 qualification scores for both groups in order to simulate the effect of raising the baseline marksmanship ability level. This has no effect on the difference between the mean scores for the two groups, however, there is a marked effect on the pass rate and the results appear to be closer to those from the 2009 study. An additional effect of this data manipulation is that the differences in qualification rates between the two groups would be highly significant after the first and second attempts (first attempt; $\chi^2 = 8.04$, $p = 0.005$ (df = 1), second attempt; $\chi^2 = 8.42$, $p = 0.004$ (df = 1). For subsequent attempts, there would be no statistically significant differences in pass rates. The data for the two groups in the 2009 study would be required in order to explore this idea further; unfortunately, the data is not available.

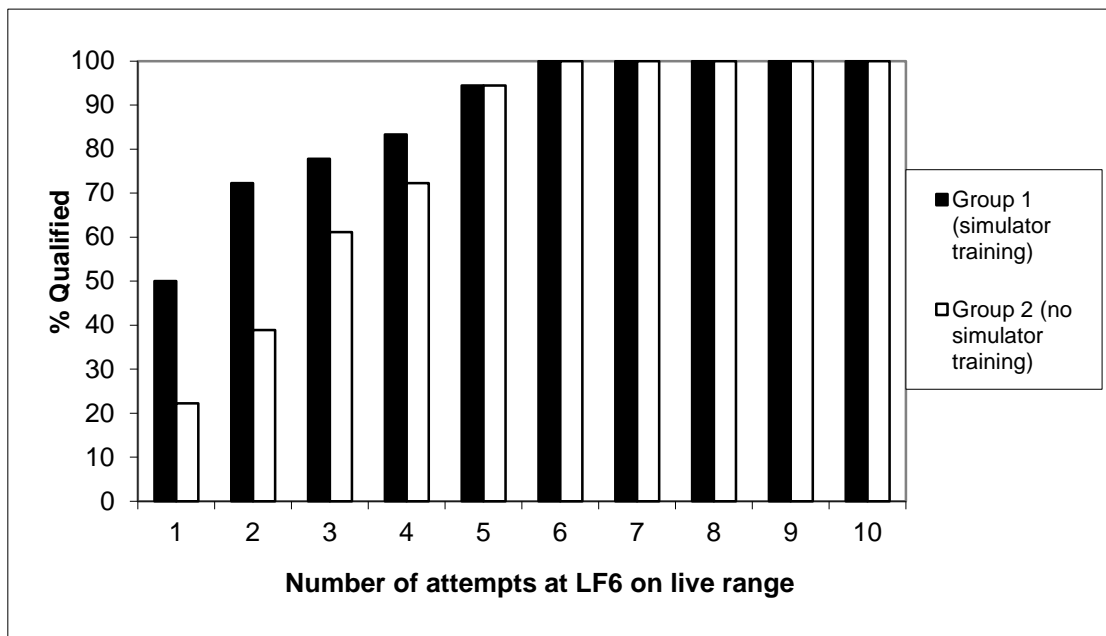


Figure 4. Pass rates for the current study after LF6 scores have been modified by adding 5 points.

Pass rates are also highly sensitive to differences in marksmanship levels between control and experimental groups due to the small sample sizes involved. With a sample size of 18 in each group, taking a firer below the passing standard from one group and swapping them with a firer above the passing standard in the other group would result in an 11% difference in pass rates between the two groups. The corresponding effect on the difference in mean scores between the groups would be far less. In the above example, if the first firer was 20 points below the passing standard and the second firer 20 points above the passing standard, the net effect on the difference between the mean scores of the two groups would be $40/18 = 2.2$ points, which is negligible.

Appendix F: Effect of live-fire on simulator performance (reverse transfer of training)

The first measure used to determine the effect of live LF6 on subsequent simulator performance is the difference in pass rates at each attempt at LF6 in the simulator. The pass rates after each LF6 practice in the simulator are shown in Figure 5³³. After three attempts, 50.0% of all trainees had passed LF6. Of these, only one trainee passed all three attempts. The pass rates for the control group (after conducting three LF6 on the live-fire range) are slightly higher than those of the experimental group at each attempt at LF6. However, none of these differences were statistically significant ($\chi^2 = 1.6$, $p = 0.21$ (df=1), first attempt; $\chi^2 = 3.6$, $p = 0.06$ (df=1), second attempt; $\chi^2 = 0.9$, $p = 0.34$ (df=1), third attempt). Consequently, the three LF6 practices conducted by the control group on the live-fire range had no measurable impact on pass rates in the simulator.

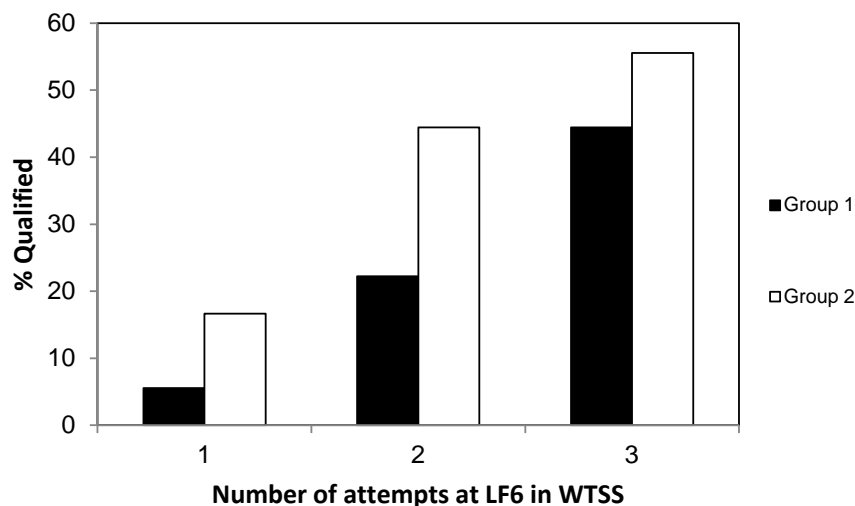


Figure 5. Pass rates for LF6 based on simulator scores

The second measure used to determine the effect of live LF6 on subsequent simulator performance is the difference in mean LF6 scores from the three LF6 simulator practices for both groups. The mean scores for all participants, as well as those for each group in the simulator are given in Table 11. Mean scores are below the pass mark of 165 points for both groups. The mean score for the control group is 6.7 points lower than that of the experimental group; this is not statistically significant ($t = 0.80$, $p = 0.44$). The lack of a significant difference between the scores for the two groups suggests that the three LF6 practices conducted by the control group on the live-fire range had no significant benefit on their subsequent performance in the simulator. That is, there is no detectable transfer of training from live-fire to the simulator for the LF6 practice. This is consistent with the trends observed with the pass rates for the two groups.

³³ Strictly speaking, during the course, trainees can only qualify on LF6 on the live range. The pass rate referred to in this instance indicates scores of 165 points or greater.

Table 11. Mean LF6 scores in simulator. Numbers in brackets are one standard deviation.

Group	First attempt	Second attempt	Third attempt	Change (first to third attempt)	Average of three attempts
Experimental group	130.6 (26.9)	148.8 (18.9)	143.5 (23.1)	12.9	140.8 (16.2)
Control group	130.3 (27.3)	141.1 (42.7)	131.1 (37.2)	0.8	134.2 (31.6)
All participants	130.4 (26.7)	144.9 (33.1)	137.1 (31.3)	6.7	137.5 (25.0)

The mean scores for each LF6 serial in the simulator are given in Table 12 for each group and for all participants. As was the case for live-fire scores, participants performed better on the 100 m serials (6, 7 and 8) than on those serials at ranges of 200 m (3, 4 and 5) and 300 m (1 and 2). There were no statistically significant differences between the scores for the experimental and control groups for any of the different serials. That is, there is no detectable transfer of training from live-fire to the simulator for any of the LF6 serials.

Table 12. Mean LF6 scores in simulator for each serial. Numbers in brackets are one standard deviation. HPS is 30 points (Serials 1 – 7) and 25 points (Serial 8).

Group	Serial							
	1 deliberate, 300 m	2 snap, 300 m	3 rapid, 200 m	4 snap, 200 m	5 rapid, 200 m	6 snap, 100 m	7 snap, 100 m	8 moving target
Experimental group	15.7 (3.3)	13.0 (4.9)	15.6 (3.8)	12.7 (3.8)	13.3 (4.4)	25.2 (3.2)	20.6 (3.7)	21.9 (2.5)
Control group	12.6 (5.9)	11.3 (5.0)	13.7 (6.6)	13.9 (6.6)	13.6 (6.4)	25.0 (6.0)	22.2 (3.8)	21.9 (2.5)
All Participants	14.2 (5.0)	12.2 (5.0)	14.6 (5.4)	13.3 (5.3)	13.5 (5.4)	25.1 (4.7)	21.4 (3.8)	21.9 (2.5)

Appendix G: Trainee observations

The following sections summarise the comments made by the participants (and training staff) in response to the questions asked at the conclusion of the study.

G.1. Comparison of simulator and live-fire experiences

There was consensus among the participants that the simulator provided a useful environment for rehearsing the LF6 procedures prior to firing the same practice on the live-fire range. However, a number of participants commented that they had difficulty seeing the LF6 targets in the simulator, particularly when targets were at longer ranges (e.g. 200 m and 300 m). This comment is consistent with the performance data (Appendix C) that showed that firers performed worse in the simulator than on the live-fire range for targets at longer ranges. It was suggested by one participant that the contrast and resolution of the background and target imagery in the simulator for the LF6 practices could be modified to improve the ability to visualise targets. The participants also noted that the recoil force of the simulated M4 weapon is lower than the recoil force of the real M4 weapon. It was highlighted by the participants that one implication of having different recoil profiles is the impact on the time to re-establish a point-of-aim and re-engage targets, which could affect subsequent LF6 performance on the live-fire range after firing in the simulator (given that some serials have targets with brief exposure times (e.g. three seconds)).

Taken together, these comments highlight limitations in the simulator, which are likely to impact on the training effectiveness of these devices. This is consistent with the overall study findings, which suggest that the simulator is not an effective substitute for live training.

G.2. LF6 serials

There were no major concerns expressed by the participants regarding their performance on specific LF6 serials they conducted in the simulator and live-fire range (beyond the issue of target visibility discussed above). However, three minor points of interest were noted. Firstly, one participant stated that the moving targets in Serial 8 appeared to move quicker on the live-fire range than the equivalent ones in the simulator; whether or not this perception is correct would need to be verified by objective testing.

Secondly, the original intention for the study methodology was to have the six LF6 practices be conducted over two days to facilitate skill acquisition and reduce the likelihood of fatigue affecting the trainees' performance. Due to the availability of the simulator at the time, all LF6 practices were conducted in one day. The participants were asked whether conducting six LF6 practices was "too much in one day" and the responses were equally split between yes and no. It may be worth noting that the amount of firing conducted during the study was not significantly different from that typically conducted on the training course. Furthermore, there was a break between each set of three LF6

practices, as well as 35-40 minutes between each detail. During these breaks, participants were not conducting any strenuous physical or mental activities. On this basis, fatigue is not likely to have affected the study outcomes. However, the level of engagement by participants in the control group when firing LF6 in the simulator may not have been particularly high, given that they had already fired 3 LF6 practices on the live-fire range, and the fact that the simulator practices did not count towards LF6 qualification.

Thirdly, participants indicated that they would have preferred to receive specific feedback about their LF6 performance on the live-fire range. However, when LF6 is conducted as a test, coaching is not permitted [22]. Therefore any LF6 practice in which coaching was provided could not count towards qualification. In addition, as mentioned previously (Section 2.3), it was agreed between the instructional staff and study team that no coaching would be provided to participants during the study. The issue of marksmanship coaching is discussed in the Section 4.5.4

G.3. M4 weapon and iron sights

There was agreement from all participants that aiming at and hitting targets with the M4 iron sights is a more difficult task compared to other weapons with optical sights (e.g. F88 Steyr). In particular, when aiming at targets with the Steyr, the target is designed to fill the reticule of the optical sight (when aiming at an LF1 target at 100 m), whereas the technique for acquiring a target with the iron sight is quite different, as discussed in Section 4.5.3.

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19. ABSTRACT Simulation is widely used within the Australian Army and other defence forces for marksmanship training. However, there is a lack of data that quantifies the training effectiveness of these devices, and informs the appropriate mix of live-fire and simulation. This report documents a study which measured the effect of additional simulator training on a basic live-fire qualification task with the M4 weapon. The study was conducted with thirty-six Australian Defence Force personnel enrolled in an Army training course. Following initial marksmanship training, one group (n=18) completed additional simulator training while the other group (n=18) proceeded straight to live-fire qualification. The group that received additional training in the simulator achieved slightly faster live-fire qualification; however trainees in both groups required numerous attempts to pass. The findings show that the simulator training had a small, positive benefit, but that the overall training method was not particularly satisfactory. The report outlines reasons for these findings and provides recommendations for future studies that could explore more effective training methodologies.					